# Climate Change in the NPLCC:

## Effects and Adaptation Approaches in Marine and Freshwater Ecosystems

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Presented to NPLCC Charter Steering Committee

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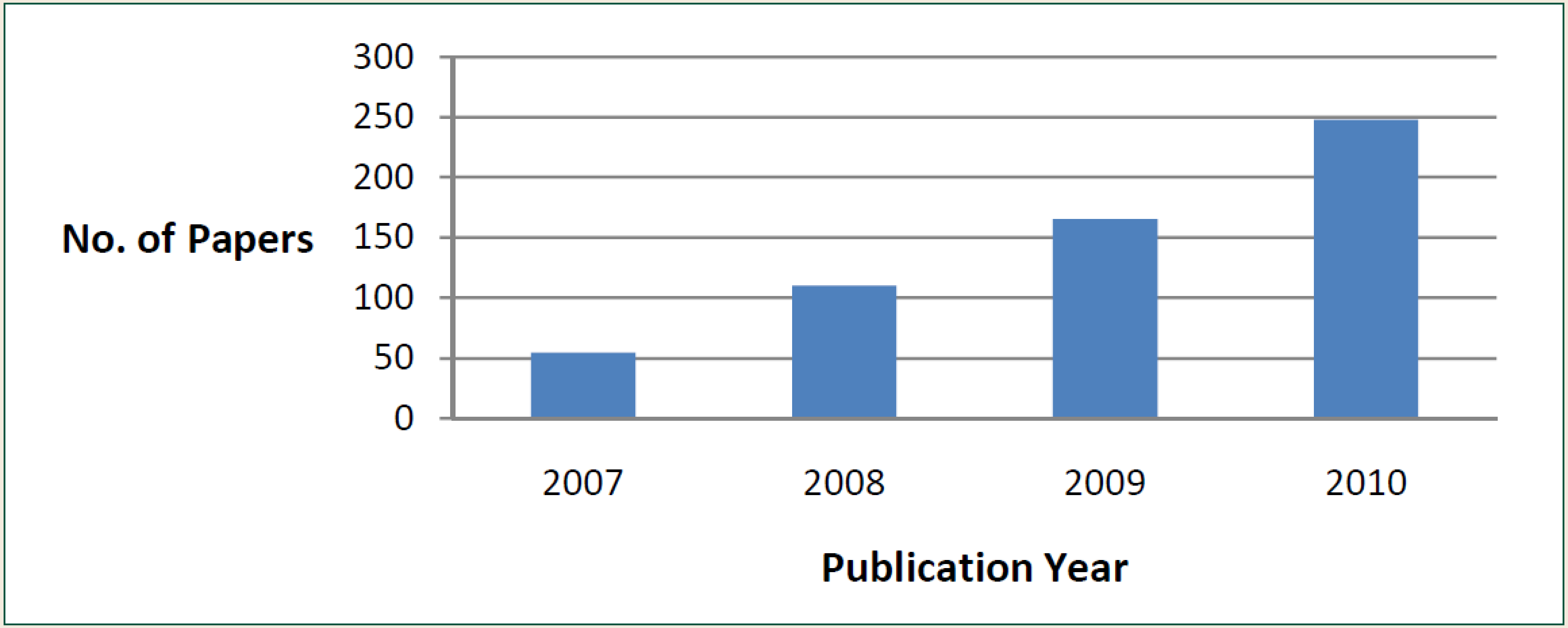
# Introduction

- The reports and focus groups inform key questions:
  - How do we prepare for climate change?
  - What research, information, and tools are needed to address climate change effects on fish and wildlife management?
  - How might planning and management change in order to prepare effectively for projected climate impacts?
- The reports organize complex and rapidly evolving bodies of literature in one place
  - Example: climate change adaptation literature

# Steady increase in climate change adaptation literature




*Source: Glick et al. 2011*

# Outline

- Compare Phase I and Phase II
- Using the reports
- Results of Phase I
- Plans and status of Phase II

# Comparing Phase I and Phase II

- Phase I
  - Identified major climate change impacts (SLR, etc.)
  - Identified implications for ecosystems, habitats, and species
  - Menu of adaptation approaches
- Phase II
  - Will identify impacts of highest priority for natural resource professionals
  - Will identify existing strategies
  - Will identify additional info, research, tools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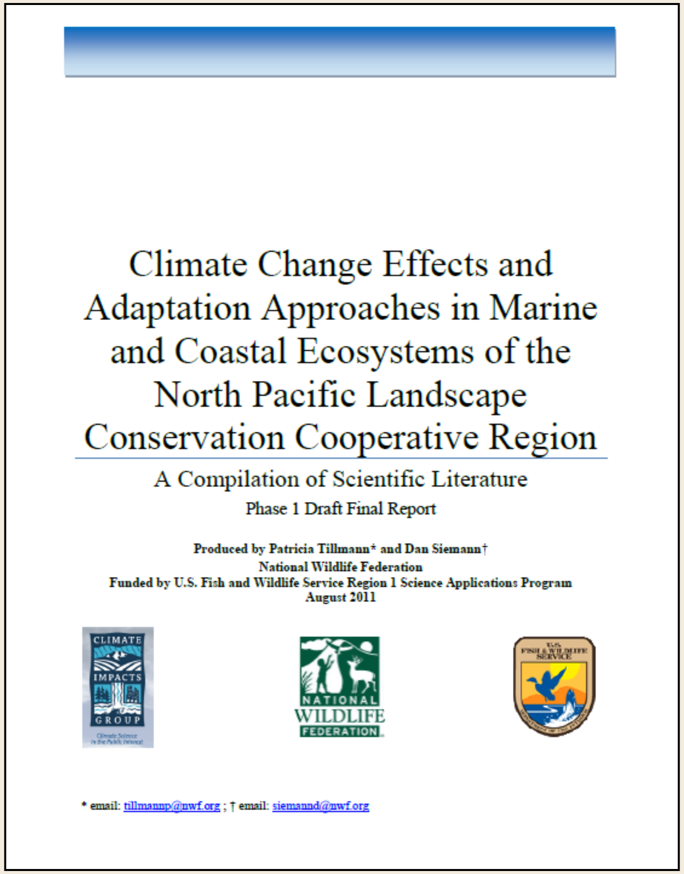
# Using the Reports: Methodology


Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region

A Compilation of Scientific Literature

Phase 1 Draft Final Report

Produced by Patricia Tillmann* and Dan Siemann†

National Wildlife Federation

Funded by U.S. Fish and Wildlife Service Region 1 Science Applications Program

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- ~280 pages
- 10 or 11 chapters
- 400+ resources
- 100+ people interviewed
- 63 reviewers
- **They are reference documents**

CONTENTS





# Using the Reports: the Table of Contents

- "Clickable" Table of Contents
- Main body of report:
  - Marine: Chapters II through VIII
  - FW: Chapters II through VII
- Example: Marine report


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(2009) note that such concomitant perturbations also complicate their detection and surveillance.[624]

Researchers suggest that, in areas with strong seasonality such as the coastal waters of the western coast of North America, organisms are susceptible to mortality when dissolved oxygen concentrations fall below 1.0 mL/L and mass mortality occurs at concentrations less than 0.5 mL/L.[625] These conditions occurred off the Oregon coast in 2002 and 2006, resulting in mass mortality of fish, Dungeness crab, and bottom-dwelling invertebrates.[626] *Please see Chapter VII Section 4 for further information on the impacts of these hypoxic events on shellfish.*

**Observed Trends**

Regional

Along the continental margins of the northeast Pacific Ocean, there is an extensive oxygen minimum zone (OMZ; ~66-4856 feet, or ~20-1480 m, deep), where dissolved oxygen falls below 0.5 mL/L.[627] Helly and Levin (2004) report the lower boundary of the OMZ would not be expected to shift significantly over seasonal to decadal intervals, although the upper boundary may experience seasonal fluctuations (e.g. of 82 feet, or 25 m, off Chile) and interannual shifts of up to 213 to 328 feet (65-100 m).[628]

Southcentral and Southeast Alaska

*Information needed.*

British Columbia

Off the coast of British Columbia, the hypoxic boundary has shoaled from about 1300 feet (400 m) to about 980 feet (300m) over fifty years (1956-2006).[629] In the depth range ~410-980 feet (125-300 m), oxygen decreased between 17% and 30% (20-40 μmol kg$^{-1}$) from 1956 to 2006.[630] Concomitant with this change is an overall trend in warming and oxygen loss in the waters below the ocean mixed layers to depths of at least 3280 feet (1000 m).[631]

Washington

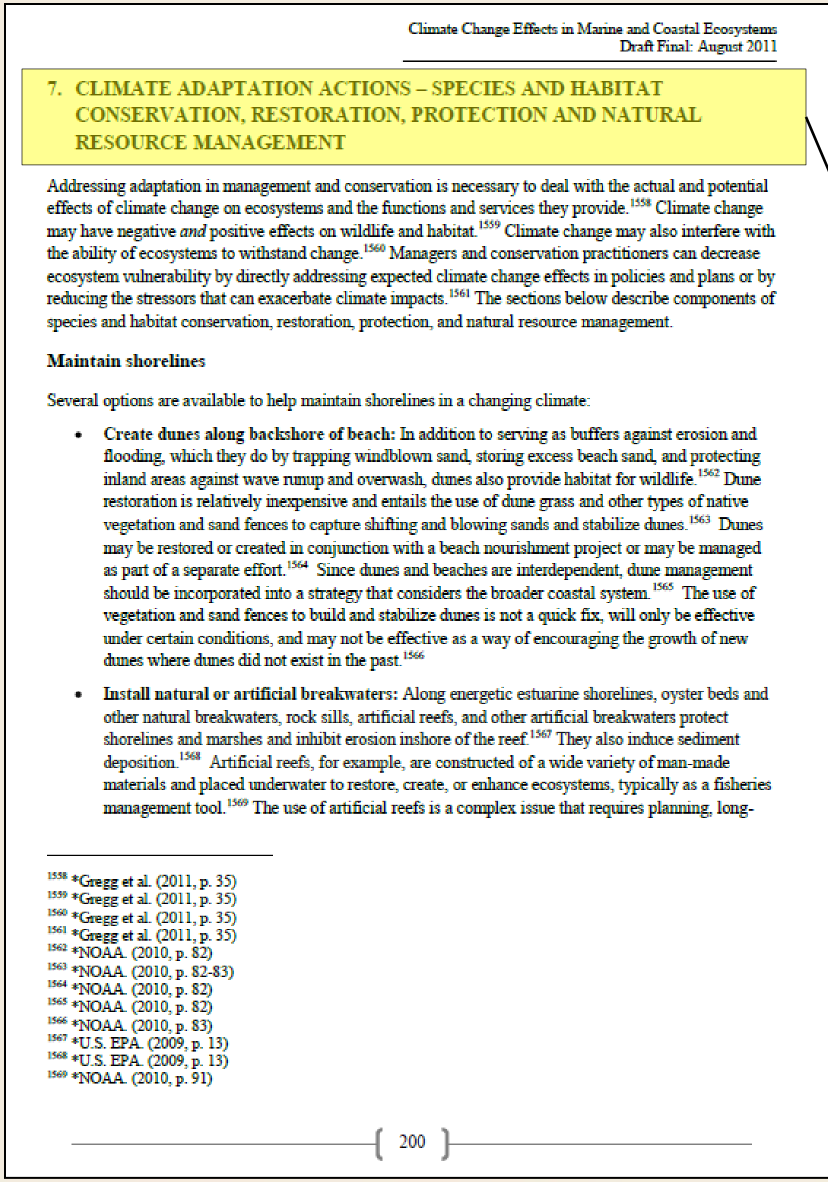
Along Washington's outer coast, the historical record (1950-1986) shows hypoxia is more prevalent and severe than that observed off the coast of northern Oregon, likely due to small-scale differences in ocean topography.[632] From 2003 to 2005, hypoxic events off the Washington coast occurred at levels

624 *Hauri et al. (2009, p. 69)
625 *Connolly et al. (2010, p. 3)
626 *Grantham et al. (2004)
627 *Grantham et al. (2004, p. 751). The authors cite Kamykowski and Zentara (1990) for this data. Please see Helly and Levin (2004, Fig. 2, p. 1163) for the depth of the OMZ in the eastern Pacific.
628 *Helly and Levin. *Global distribution of naturally occurring marine hypoxia on continental margins.* (2004, p. 1165)
629 *Whitney, Freeland and Robert. (2007, p. 179)
630 *Whitney, Freeland and Robert. (2007, p. 196)
631 *Whitney, Freeland and Robert. (2007, p. 179)
632 *Connolly et al. (2010, p. 1, 7)



# Using the Marine Report: Ch. II-VII

- Primary organization is by:
  - Observed trends
  - Future projections
  - Information gaps
- Within each heading, information is organized geographically, from north to south
- In general, Chapters II through V:
  - Global
  - Southcentral and Southeast Alaska
  - British Columbia
  - Washington
  - Oregon
  - Northwest California
- In general, Chapters VI and VII:
  - Global
  - Gulf of Alaska Large Marine Ecosystem
  - California Current Large Marine Ecosystem



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7. CLIMATE ADAPTATION ACTIONS – SPECIES AND HABITAT CONSERVATION, RESTORATION, PROTECTION AND NATURAL RESOURCE MANAGEMENT

Addressing adaptation in management and conservation is necessary to deal with the actual and potential effects of climate change on ecosystems and the functions and services they provide.[1558] Climate change may have negative *and* positive effects on wildlife and habitat.[1559] Climate change may also interfere with the ability of ecosystems to withstand change.[1560] Managers and conservation practitioners can decrease ecosystem vulnerability by directly addressing expected climate change effects in policies and plans or by reducing the stressors that can exacerbate climate impacts.[1561] The sections below describe components of species and habitat conservation, restoration, protection, and natural resource management.

**Maintain shorelines**

Several options are available to help maintain shorelines in a changing climate:

- **Create dunes along backshore of beach:** In addition to serving as buffers against erosion and flooding, which they do by trapping windblown sand, storing excess beach sand, and protecting inland areas against wave runup and overwash, dunes also provide habitat for wildlife.[1562] Dune restoration is relatively inexpensive and entails the use of dune grass and other types of native vegetation and sand fences to capture shifting and blowing sands and stabilize dunes.[1563] Dunes may be restored or created in conjunction with a beach nourishment project or may be managed as part of a separate effort.[1564] Since dunes and beaches are interdependent, dune management should be incorporated into a strategy that considers the broader coastal system.[1565] The use of vegetation and sand fences to build and stabilize dunes is not a quick fix, will only be effective under certain conditions, and may not be effective as a way of encouraging the growth of new dunes where dunes did not exist in the past.[1566]
- **Install natural or artificial breakwaters:** Along energetic estuarine shorelines, oyster beds and other natural breakwaters, rock sills, artificial reefs, and other artificial breakwaters protect shorelines and marshes and inhibit erosion inshore of the reef.[1567] They also induce sediment deposition.[1568] Artificial reefs, for example, are constructed of a wide variety of man-made materials and placed underwater to restore, create, or enhance ecosystems, typically as a fisheries management tool.[1569] The use of artificial reefs is a complex issue that requires planning, long-

[1558] *Gregg et al. (2011, p. 35)
[1559] *Gregg et al. (2011, p. 35)
[1560] *Gregg et al. (2011, p. 35)
[1561] *Gregg et al. (2011, p. 35)
[1562] *NOAA (2010, p. 82)
[1563] *NOAA (2010, p. 82-83)
[1564] *NOAA (2010, p. 82)
[1565] *NOAA (2010, p. 82)
[1566] *NOAA (2010, p. 83)
[1567] *U.S. EPA (2009, p. 13)
[1568] *U.S. EPA (2009, p. 13)
[1569] *NOAA (2010, p. 91)

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# Using the Marine Report: Ch. VIII

- Primary organization is by adaptation approach:
  - Information gathering and capacity building
  - Monitoring and planning
  - Infrastructure and development
  - Governance, policy, and law
  - Species and habitat conservation, restoration, protection and natural resource management
- The final section, Section 8, provides status updates on adaptation strategies and plans in the region

Digital Vision

# Using the Reports: Citations & References

[239] * Wootton, Pfister and Forester. (2008, Table 1, p. 18849)
[240] * Wootton, Pfister and Forester. (2008, p. 18849). The authors cite Orr et al. (2005) for information on previous model predictions.
[241] * Wootton, Pfister and Forester. (2008, p. 18849). The authors cite Orr et al. (2005) for the value of -0.0019.
[242] * Wootton, Pfister and Forester. (2008, p. 18851). The authors cite Solomon et al. (2007), Dore et al. (2003), Pelejero et al. (2005), and Feely et al. (2008) for this information.
[243] * Wootton, Pfister and Forester. (2008, p. 18851)
[244] * Wootton, Pfister and Forester. (2008, p. 18851). The authors cite Solomon et al. (2007) and Santana-Casiano et al. (2007) for this information.
[245] *Byrne et al. *Direct observations of basin-wide acidification of the North Pacific Ocean.* (2010, p. 3)
[246] *Feely et al. *Ocean acidification: present conditions and future changes in a high $CO_2$ world.* (2009, p. 37)
[247] *Meehl et al. *Climate Change 2007: The Physical Science Basis: Global Climate Projections.* (2007, p. 793)
[248] *Cooley et al. *Ocean acidification's potential to alter global marine ecosystem services.* (2009, p. 172-173). The authors cite Cooley and Doney (2009) for this information.
[249] *Meehl et al. (2007, p. 793)

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XI. BIBLIOGRAPHY

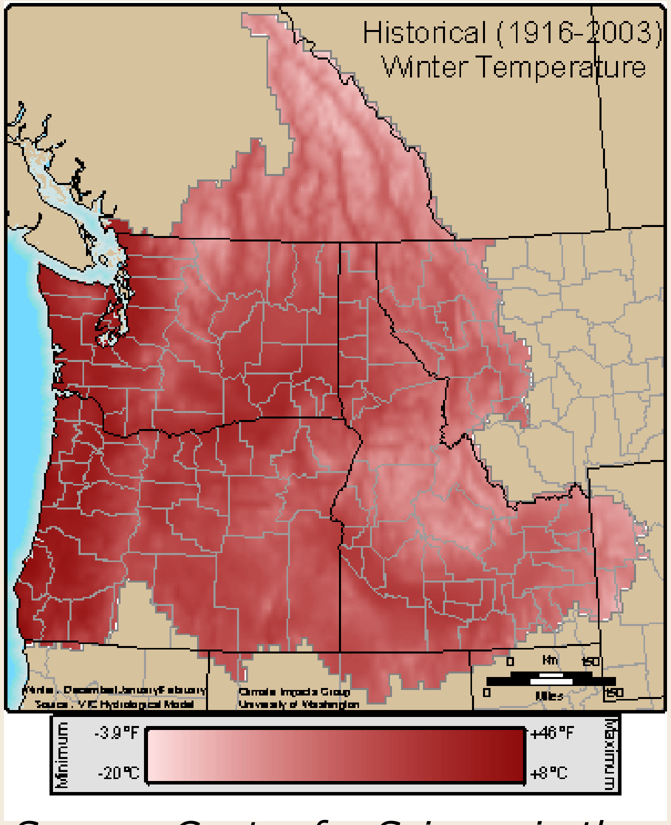
Abeysirigunawardena, Dilumie S., and Ian J. Walker. "Sea level responses to climatic variability and change in northern British Columbia." *Atmosphere-Ocean* 46, no. 3 (2008): 277-296.

Ackerly, D. D., et al. "The geography of climate change: implications for conservation biogeography (Supplemental Information)." *Diversity and Distributions*, 2010: 16, http://onlinelibrary.wiley.com/store/10.1111/j.1472-4642.2010.00654.x/asset/supinfo/DDI_654_sm_Data_S1andFig_S1-S8.pdf?v=1&s=93f8310b31bb81d495bae87579a8d7f4d710ca3e (accessed 6.8.2011).

- >90% sentences cited
- Footnotes increase usefulness
- Bibliography is organized by author, not by footnote number.

# Phase I Results: Summary of Climate Change Impacts

- Continued increase in $CO_2$
  - 392 ppm → >600 ppm
- Continued increase in temperature in NPLCC
  - 2100: +3.1 to +6.1°F, up to +13°F in AK
- Enhanced precipitation variability in NPLCC
  - Annual PNW, 2080s: -10 to +20%
  - Annual BC Coast, 2050: +6%
  - Annual CA, 2050: -12 to -35%
  - Increases in winter and decreases in summer
  - **Data does not include Alaska**




*Source: Center for Science in the Earth System, Univ.of Washington*

## Phase I Results: Summary of Climate Change Impacts (Marine)

| *Impact* | *Observed Trends* | *Future Projections* |
|---|---|---|
| **Ocean acidification (represented by pH)** | ~8.1, regional variation (Hood Canal: 7.39) | ~556 ppm $CO_2$: ~7.9<br>~834 ppm $CO_2$: ~7.7-7.8 |
| **Increasing sea surface temperature** | BC: +0.52 to +1.7°F (1917-2003); OR: +1.8°F (1997-2005 *vs.* 1961-1971) | Winter 2040-2049: +1.8 to +2.9°F (1980-1999 baseline) |
| **Sea level change** | Generally less than 1961-2003 global average | 2100, AK: -25 to -41”<br>2100, Other: +4.3 to +55” |
| Altered ocean currents | CA: stronger, deeper thermocline (1950-1993) | Information needed. Maybe > natural variability extremes. |
| Altered frequency & severity of storms | OR & WA wave heights: +8 ft. , 65% more force | Likely more intense overall. Frequency may increase in north, decrease elsewhere. |
| Altered patterns of coastal upwelling | Observed region-wide | Increased intensity & favorable winds, but highly uncertain. |
| Altered patterns of coastal hypoxia/anoxia | WA: DO <0.5 mL/L (2006)<br>OR: DO 0.21-1.57 mL/L (2002) | Information needed.<br>May increase. |

*Note: Results for Altered Hydrology are summarized in freshwater table.

# Phase I Results: Summary of Climate Change Impacts (FW)

| *Impact* | *Observed Trends* | *Future Projections* |
|---|---|---|
| Reduced snowpack | -1.5 feet snowfall (Juneau); -16% to -25% SWE (BC, PNW) | 2X $CO_2$: -73% (N. Coast CA); By 2100: -28% (*vs.* 1961-90, Fraser); -56 to -70% SWE (*vs.* 1917-2006, WA) |
| **Altered runoff/ streamflow amount** | PS: -13% annual inflow<br>Region-wide: Winter increases & summer decreases | By 2100: mean +1.8 to +5.1% (*vs.* 1961-90, Fraser); -50% 7Q2 (WA) |
| **Altered runoff/ streamflow timing** | CT*: Up to >20 days earlier (snow basins) or later (non-snow basins) | 2099: 10-20 days earlier in AK/BC, 30-40 days earlier elsewhere (*vs.* 1995) |
| **Increased flooding and extreme flow** | Western U.S.: increased flood risk in rain & rain-snow basins | 2040s: +5 to +22% (1916-2006; Ross Dam WA); Portland: 25-year storm more frequent |
| Increased water temperature | Lake WA: +1.2 to +1.6°F (annually); w. WA: <68°F | By 2100: many streams >68°F (Fraser, w. WA & OR) |
| Reduced glacier size and abundance | N. Cascades: 53 glaciers gone, 75% thinning; OR: 40-60% loss | Losses by 2100: Bridge Gl. >30%, N. Cascades 75%, Mt. Shasta 65-100% |
| Changes in water quality | P & N low in Rogue & Klamath R.; Columbia R.: 0.26 mg/L $NO_3$-N; 0.06 mg/L total P | Information needed. Increased flows and reduced flows: dilute nutrients or increase sediments. |
| Altered groundwater levels, recharge, & salinity | Saltwater intrusion: 9% (36 of 379 wells, Island Cty, WA) | Timing mimics streamflow changes. Increased saltwater intrusion. |

*CT = Center of mass of annual flow

# Ocean Acidification

Observed pH Trends
- Regional: 8.1
- Hood Canal: 7.39
- Tatoosh Island:
  - daily & yearly variation



would be expected from anthropogenic carbon dioxide uptake alone.[224] For example, in the deep waters of the Hood Canal sub-basin (> ~66 feet, 20 m):

- pH decreased from an estimated pre-industrial winter value of 7.60 to 7.56 ± 0.06 in February 2008, and aragonite saturation decreased from 0.66 to 0.61 ± 0.06.[225]
- pH declined from an estimated pre-industrial summer value of 7.41 to 7.39 ± 0.05 in August 2008, and aragonite saturation decreased from 1.73 to 1.50 ± 0.66.[226]
- Feely et al. (2010) estimate that ocean acidification can account for twenty-four to forty-nine percent of the observed decline in pH.[227] The remaining change in pH between when seawater enters the sound and when it reaches Hood Canal results from remineralization of organic matter due to natural or anthropogenically stimulated respiration processes within Puget Sound.[228]

Researchers at Tatoosh Island on the northwestern tip of Washington State (near Neah Bay) observed that pH declined with increasing atmospheric $CO_2$ levels and varied substantially in response to biological processes and physical conditions that fluctuate over multiple time scales.[229] Examination of 24,519 measurements of coastal ocean pH spanning eight years (2000-2007) revealed several patterns:[230]

- pH exhibited a pronounced 24-hour cycle, spanning 0.24 units during a typical day.[231] This diurnal oscillation is readily explained by daily variation in photosynthesis and background respiration: water pH increases as $CO_2$ is taken up, via photosynthesis, over the course of the day, and then declines as respiration and diffusion from the atmosphere replenish $CO_2$ overnight.[232]
- pH fluctuated substantially among days and years, ranging across a unit or more within any given year and 1.5 units over the study period.[233]
- When the entire temporal span of the data was considered, a general declining trend in pH became apparent.[234] The decline is significant ($P<0.05$).[235]

**Table 7.** Absolute and relative changes in pH, carbonate ion, and aragonite($\Omega_{arag}$) and calcite ($\Omega_{calc}$) saturation states for three $CO_2$ levels (2005, and 2X and 3X pre-industrial* levels) in the North Pacific and Subpolar Pacific Oceans.

** One reviewer suggested using ppm for $CO_2$ values. Feely, Doney and Cooley do not provide ppm values for $CO_2$. However, using the IPCC value of 278 ppm for pre-industrial $CO_2$, 2X would be 2*278=556 ppm $CO_2$ and 3X would be 3*278=834 ppm $CO_2$.*

| *Ocean* | *$CO_2$* | *pH* | *ΔpH* | *Carbonate ion (μmol/kg)* | *ΔCarbonate* | *$\Omega_{arag}$* | *Δ $\Omega_{arag}$* | *$\Omega_{calc}$* | *Δ $\Omega_{calc}$* |
|---|---|---|---|---|---|---|---|---|---|
| North Pacific (>50°N) | 2005 | 8.1 | | 92.3 | | 1.4 | | 2.24 | |
| | 2X | 7.885 | -0.15 | 67.8 | -24.5 (-26.5%) | 1.03 | -0.37 (-26.5%) | 1.65 | -0.59 (-26.5%) |
| | 3X | 7.719 | -0.31 | 47.5 | -44.8 (-48.5%) | 0.72 | -0.68 (-48.5%) | 1.15 | -1.09 (-48.5%) |
| Subpolar Pacific | 2005 | 8.0 | | 134.5 | | 2.06 | | 3.24 | |
| | 2X | 7.913 | -0.14 | 101.3 | -33.2 (-24.7%) | 1.55 | -0.51 (-24.7%) | 2.44 | -0.80 (-24.7%) |
| | 3X | 7.756 | -0.30 | 72.5 | -62.0 (-46.1%) | 1.11 | -0.95 (-46.1%) | 1.75 | -1.49 (-46.1%) |

*Source: Modified from Feely, Doney and Cooley (2009, Table 2, p. 46) by authors of this report.*

Future Projections
- North of 50°N: 7.7
- Rest of NPLCC: 7.8

Implications
- Salmon prey
- Interactions with existing stressors

# Increasing sea surface temperature

**Table 8.** Linear decadal trends in SST in the Northern Hemisphere and Globally.
(°F with °C in parentheses; *significant at the < 1% level, †significant at the 1-5% level)

| | Temperature Trend Per Decade | | |
|---|---|---|---|
| | 1850-2005 | 1901-2005 | 1979-2005 |
| Northern Hemisphere | 0.076 ± 0.029* (0.042 ± 0.016) | 0.13 ± 0.052* (0.071 ± 0.029) | 0.342 ± 0.241† (0.190 ± 0.134) |
| Globe | 0.068 ± 0.020* (0.038 ± 0.011) | 0.12 ± 0.027* (0.067 ± 0.015) | 0.239 ± 0.085* (0.133 ± 0.047) |

*Source: Modified from Trenberth et al. (2007, Table 3.2, p. 243) by authors of this report.*

*Notes:* SST are those produced by the United Kingdom Meteorological Office (UKMO) under the HadSST2 (Rayner et al. 2006). Annual averages, with estimates of uncertainties for HadSST2, were used to estimate trends. Trends with 5 to 95% confidence intervals and levels of significance (**bold: <1%**; *italic, 1-5%*) were estimated by Restricted Maximum Likelihood (REML), which allows for serial correlation (first order autoregression AR1) in the residuals of the data about the linear trend. The Durbin Watson D-statistic (not shown) for the residuals, after allowing for first-order serial correlation, never indicates significant positive correlation.

- Observed Trends
  - Increased warming over 20th century
  - Global: +1.1°F
  - BC: +0.52 to +1.7°F
  - OR: +1.8°F
- Future Projections
  - Global: +4.7°F
  - North Pacific: +1.8 to 2.9°F
  - Warmer max & min
  - BC/WA: +2.2 to 2.7°F

# Sea level change

Observed Trends

- SLR generally *less than* 1961-2003 global average
- *Greater than* global average in Cordova, Toke Point, South Beach, and PNW overall
- *Declines* in most of AK, Tofino, and Neah Bay
- *CA inconclusive*

**Table 12.** SLR Trends in British Columbia, 1909-2006.
(CI = Confidence Interval. Table created by authors of this report.)

| *Location* | *Time period(s)** | *Mean ± 95% CI* (***measured in inches per year***) | *Mean ± 95% CI* (***measured in millimeters per year***) |
|---|---|---|---|
| Prince Rupert | 1909-2006 | - 0.0429 ± 0.011 | - 1.09 ± 0.27 |
| | 1909-2003 | 0.04 ± 0.02 | 1 ± 0.4 |
| | 1939-2003 | 0.055 ± 0.02 | 1.4 ± 0.6 |
| | 1913-2004 | 0.039** | 0.98** |
| Tofino | 1909-2006 | - 0.0626 ± 0.013 | - 1.59 ± 0.32 |
| | 1910-2004 | - 0.0661** | -1.68** |
| Vancouver | 1910-1999 | 0.015 ± 0.011 | 0.37 ± 0.28 |
| | 1911-2004 | 0.02** | 0.4** |
| Victoria | 1909-1999 | 0.031 ± 0.0098 | 0.80 ± 0.25 |
| | 1910-2003 | 0.024** | 0.62** |
| Global average | 1961-2003 | 0.071 ± 0.02† | 1.8 ± 0.5† |
| | 1993-2003 | 0.12 ± 0.03† | 3.1 ± 0.7† |

*All values for 1909-2006 are NOAA values, as are values for Vancouver (1910-1999) and Victoria (1909-1999). Values for 1913-2004 in Prince Rupert, 1910-2004 in Tofino, 1911-2004 in Vancouver, and 1910-2003 in Victoria are reported by the B.C. Ministry of Environment . Values for 1909-2003 and 1939-2003 are reported by Abeysirigunawardena and Walker. .

**With the exception of Vancouver (chance of no trend >0.1), all stations have a chance of no trend less than 0.05: Prince Rupert (<0.05), Tofino (<0.001), and Victoria (<0.01).

†Global averages are reported as 90% CI.

# Sea level change

Future Projections for 2100

- Global: +8.1 to 70”
- AK: -25.2 to 40.8”
- BC: +31.2 to 46.8”
- PS Basin: +50”
- WA NW Coast: +35”
- OR/CA: Up to +55”

Implications

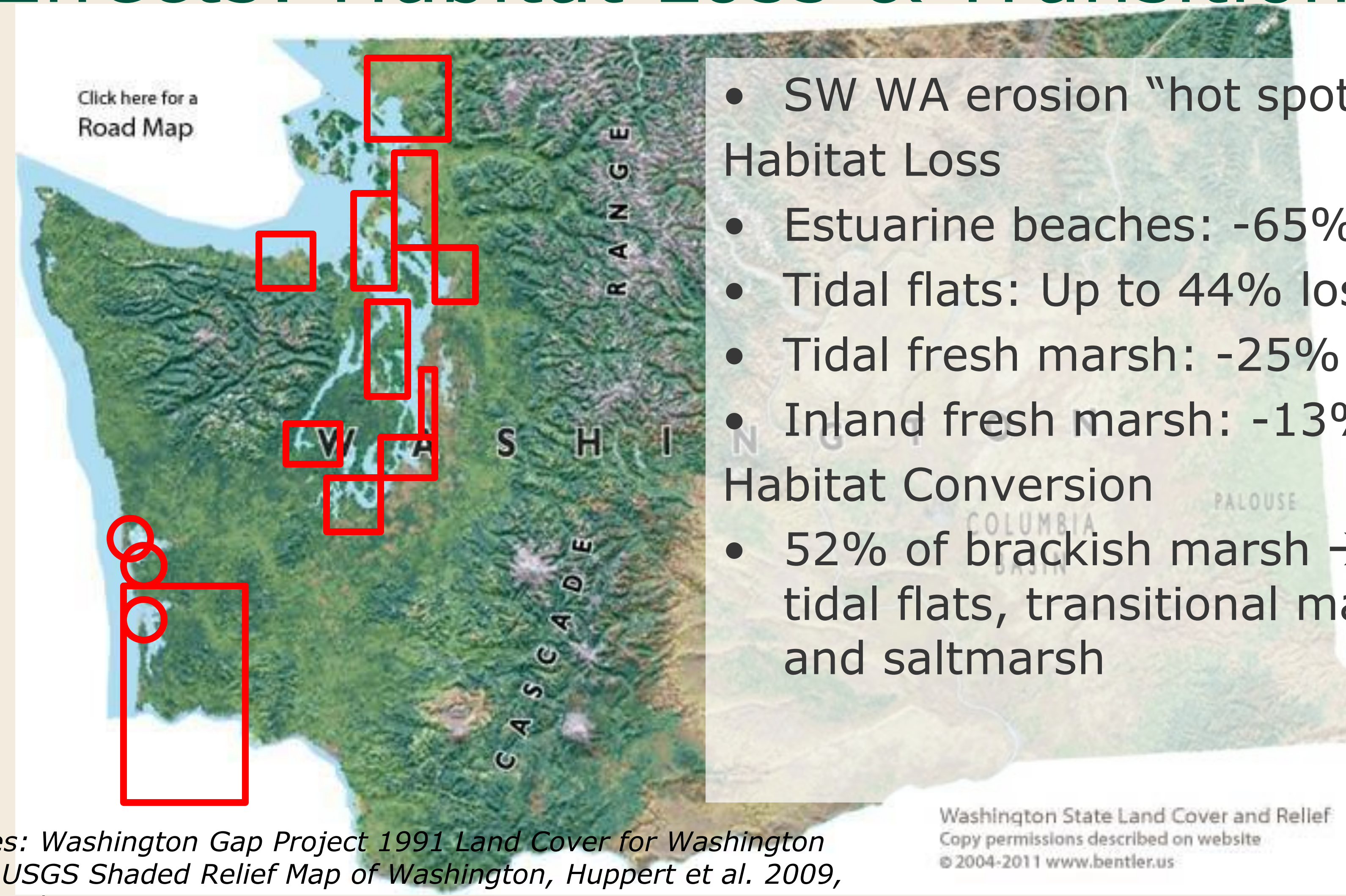
- Coastal erosion
- Coastal squeeze
- Habitat loss & transition

**Table 16.** Global Average Sea level Rise 1961-2100.
(inches with cm in parentheses. Table created by authors of this report.)

| Scenario or Year(s) | IPCC model-based range (2090-2099 relative to 1980-1999) | Meehl et al. (2005) (2100 relative to 1999 levels) | Rahmstorf (2007) (2100 relative to 1990 levels) | Vermeer and Rahmstorf (2009) (2100 relative to 1990 levels)* | Grinsted et al. (2009) (2090-2099 relative to 1980-1999) |
|---|---|---|---|---|---|
| 1961-2003 | 0.051 – 0.091 inches/yr (1.3 – 2.3 mm/yr) | | | | |
| 1993-2003 | 0.094 – 0.15 inches/yr (2.4 – 3.8 mm/yr) | | | | |
| 2100 | | | 20 – 55 (50 – 140) | | |
| B1 | 7.1 – 15 (18 – 38) | PCM: 5.1 (13) CCSM3: 7.1 (18) | | 32 – 52 (81-131) | 28 – 42 (72-107) |
| A1T | 7.8 – 18 (20 – 45) | | | 38 – 62 (97-158) | 35 – 51 (89-130) |
| B2 | 7.8 – 17 (20 – 43) | | | 35 – 57 (89-145) | 32 – 47 (82-120) |
| A1B | 8.3 – 19 (21 – 48) | PCM: 7.1 (18) CCSM3: 9.8 (25) | | 38 – 61 (97-156) | 36 – 52 (91-132) |
| A2 | 8.1 – 20 8.2 (23 – 51) | PCM: 7.5 (19) CCSM3:12 (30) | | 39 – 61 (98-155) | 37 – 54 (93-136) |
| A1F1 | 10 – 23 (26 – 59) | | | 44 – 70 (113-179) | 43 – 63 (110-160) |

*The model average associated with each scenario is 41” (104 cm) for the B1 scenario, 45” (114 cm) for the B2 scenario, 49” (124 cm) for the A1T, A1B, and A2 scenarios, and 56” (143 cm) for the A1F1 scenario.

# Effects: Habitat Loss & Transition




- SW WA erosion "hot spots"

Habitat Loss

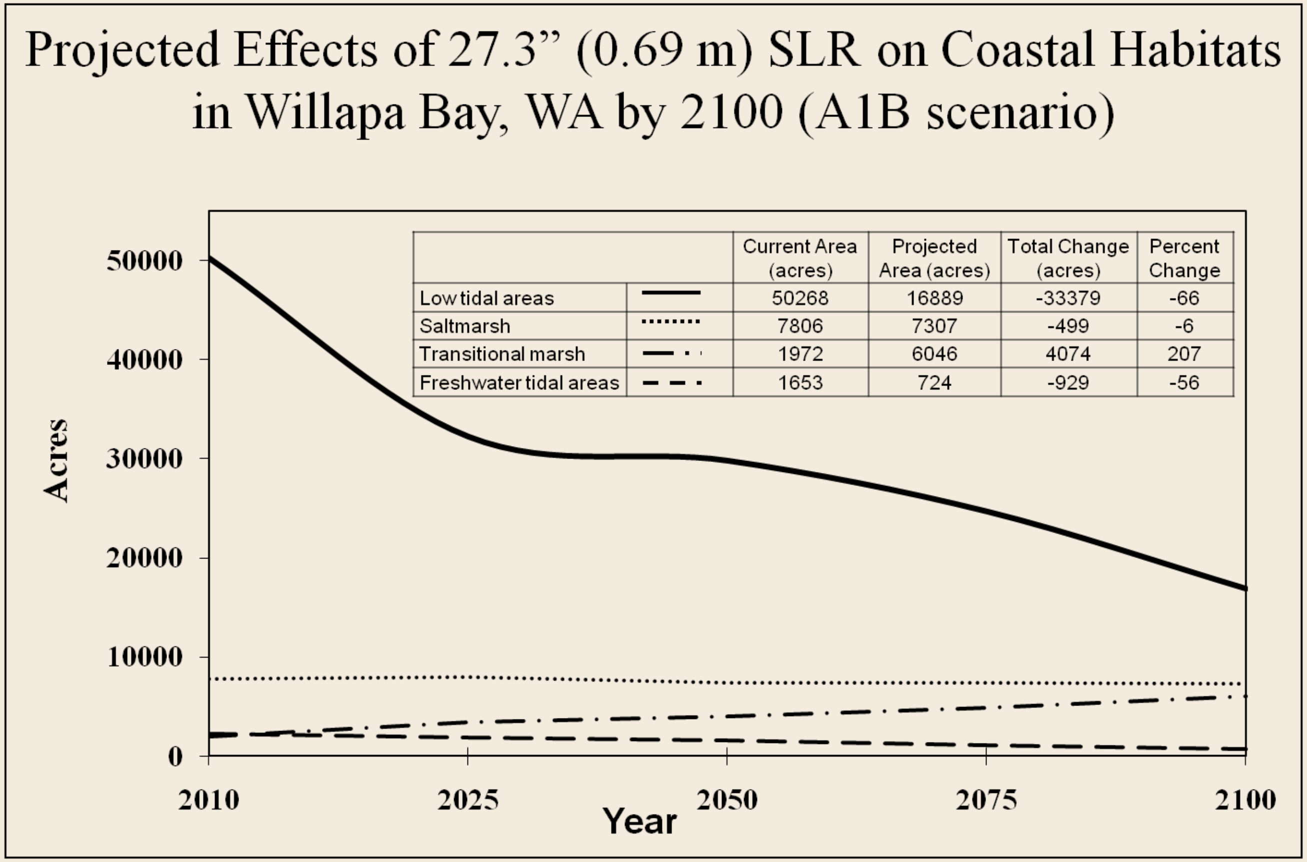
- Estuarine beaches: -65%
- Tidal flats: Up to 44% loss
- Tidal fresh marsh: -25%
- Inland fresh marsh: -13%

Habitat Conversion

- 52% of brackish marsh → tidal flats, transitional marsh and saltmarsh

*Sources: Washington Gap Project 1991 Land Cover for Washington State, USGS Shaded Relief Map of Washington, Huppert et al. 2009, Glick et al. 2007*

# Effects: Habitat Loss & Transition




| | Current Area (acres) | Projected Area (acres) | Total Change (acres) | Percent Change |
|---|---|---|---|---|
| Low tidal areas | 50268 | 16889 | -33379 | -66 |
| Saltmarsh | 7806 | 7307 | -499 | -6 |
| Transitional marsh | 1972 | 6046 | 4074 | 207 |
| Freshwater tidal areas | 1653 | 724 | -929 | -56 |

*Data Source: Ducks Unlimited*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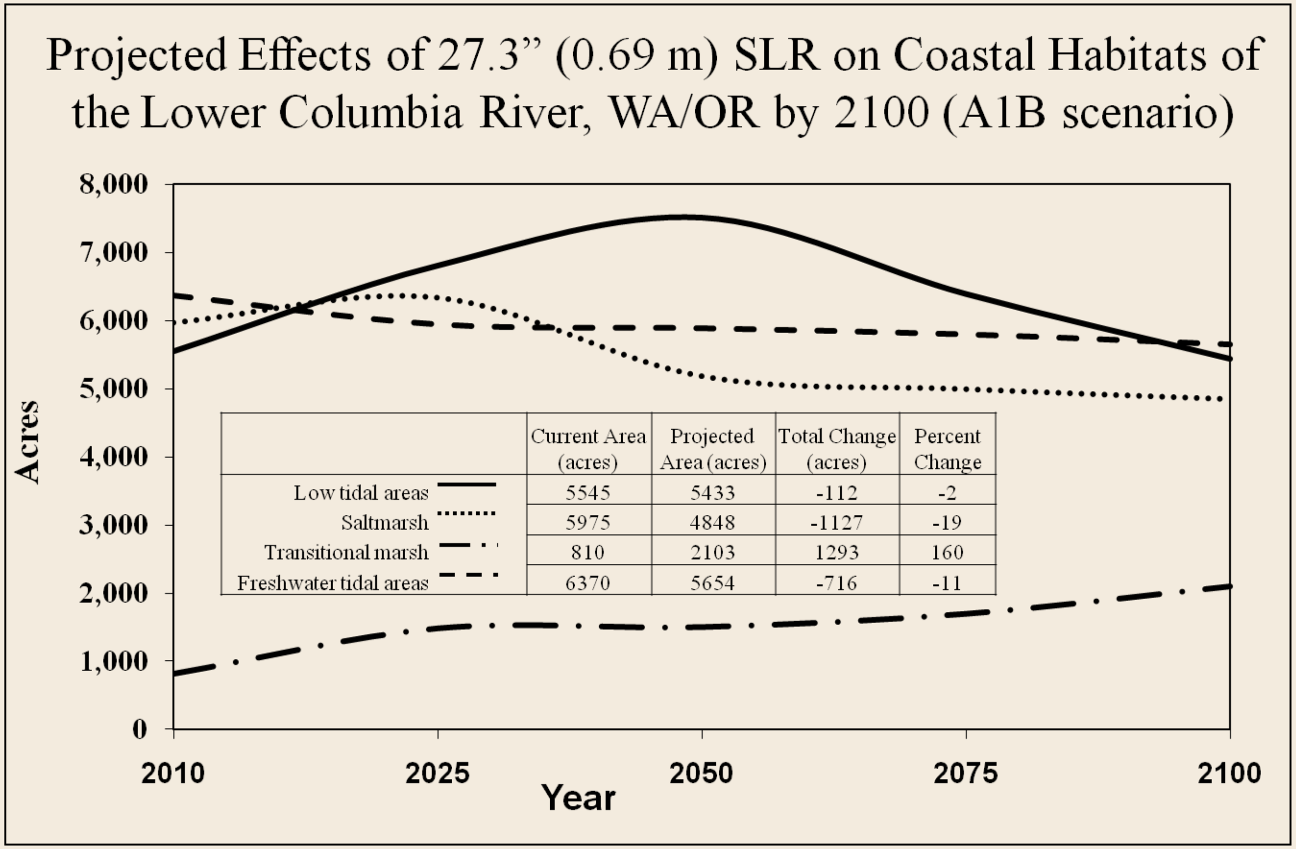
# Effects: Habitat Loss & Transition

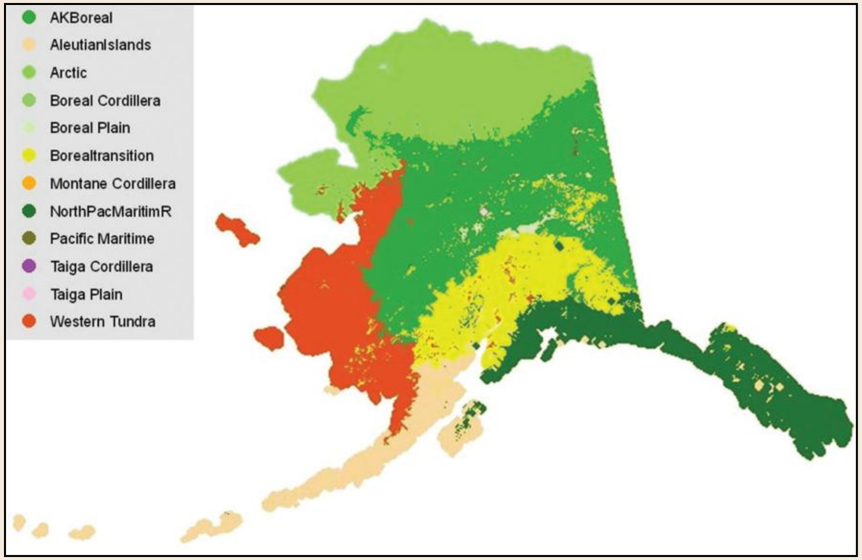



| | Current Area (acres) | Projected Area (acres) | Total Change (acres) | Percent Change |
|---|---|---|---|---|
| Low tidal areas | 5545 | 5433 | -112 | -2 |
| Saltmarsh | 5975 | 4848 | -1127 | -19 |
| Transitional marsh | 810 | 2103 | 1293 | 160 |
| Freshwater tidal areas | 6370 | 5654 | -716 | -11 |

*Data Source: Ducks Unlimited*

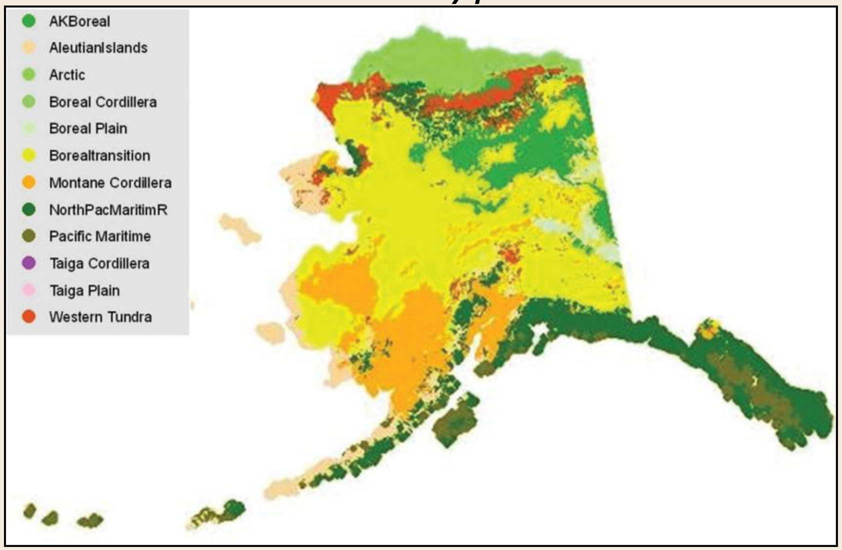
# Effects: Habitat Loss & Transition

*2000-2009 Biome Types*




*Source: Murphy et al. (2010)*

*2090-2099 Biome Types*




*Source: Murphy et al. (2010)*

Modeling indicates nearly half of southeast Alaska shifts from North Pacific Maritime to the Canadian Pacific Maritime

# Altered runoff/streamflow amount, timing, & frequency



**Table 8.** Observed trends in the timing, amount, and frequency of runoff and streamflow, NPLCC region.
*Note: Table created by authors of this report. Table continues on next page.*

| Observed Trends | Location | Study Period | Citation |
|---|---|---|---|
| TIMING | | | |
| • The peak of spring runoff shifted from a few days to as many as thirty days earlier.[296] | NPLCC region | 1950-2000 | Karl et al. (2009) |
| • The dates of maximum snowpack and 90% melt-out have shifted five days earlier.[297] | Cascade Mountains | 1930-2007 | Stoelinga et al (2010) |
| • *Summer* melt events in Thunder Creek accounted for 17 of the 26 (65%) highest peak flows from 1950-1975, but from 1984 to 2004, 8 of 13 (62%) yearly peak flow events resulted from *winter* rain on snow melt events, the other five (38%) occurring in summer.[298] • The earlier release of meltwater has become more pronounced since 1990.[299] | North Cascade Mountains, WA | 1950-2004 | Pelto (2008) |
| • A twelve day shift toward earlier onset of snowmelt | Puget Sound WA | 1948-2003 | Snover et al. (2005) |
| AMOUNT | | | |
| • Trends in the lower part of the distribution of annual streamflow show strong and significant declines at a large majority (72%) of gauging stations.[300] • In addition, the driest 25% of years are becoming substantially drier.[301] | Pacific Northwest | 1948-2006 | Luce and Holden (2009) |
| • An 18% decline in the fraction of annual river flow entering Puget Sound between June and September.[302] • A 13% decline in total inflow due to changes in precipitation in Puget Sound.[303] | Puget Sound WA | 1948-2003 | Snover et al. (2005) |
| • Increased mean winter (Nov-March) streamflow: +17% in Newhalem Creek, +20% in Thunder Creek, +13.8% in all six basins studied,[304] and +0.344%/year (range: 0.01%/yr to 0.55%/yr) across all six basins studied.[305] • Declining mean summer streamflow: -28% in Newhalem Creek, -3% in Thunder Creek,[306] and | North Cascade Mountains, WA | 1963-2003 | Pelto (2008) |

Climate Change Effects in Freshwater Ecosystems
Draft Final: August 2011

| Observed Trends | Location | Study Period | Citation |
|---|---|---|---|
| -0.48%/yr (range: -0.04%/yr to -1.11%/yr) in all six basins studied.[307] • Mean spring streamflow was nearly unchanged: +0.0233%/yr (range: -0.01%/yr to +0.31%/yr)[308] | | | |
| • Depending on the basin, glacial contribution to summer streamflow was 1-12% above normal.[309] | North Cascades, WA | 1993-2009 | Riedel & Larrabee (2011) |
| • In the Cascade Range of western Oregon, relative streamflow in August decreased significantly in two snow-dominated basins, but not in two rain-dominated basins.[310] | Cascade Mountains, western OR | 20th century | Chang and Jones (2010) citing Jefferson et al. (2006) |
| • Runoff ratios and baseflow have declined significantly during spring, but they have not changed during summer or winter.[311] | H.J. Andrews Experimental Forest, OR | 1952-2006 | Chang and Jones (2010) |
| FREQUENCY | | | |
| • An increase in the likelihood of both low and unusually high daily flow events. | Puget Sound WA | 1948-2003 | Snover et al. (2005) |

Primary source of change:
warmer temperatures → precipitation falls as rain rather than snow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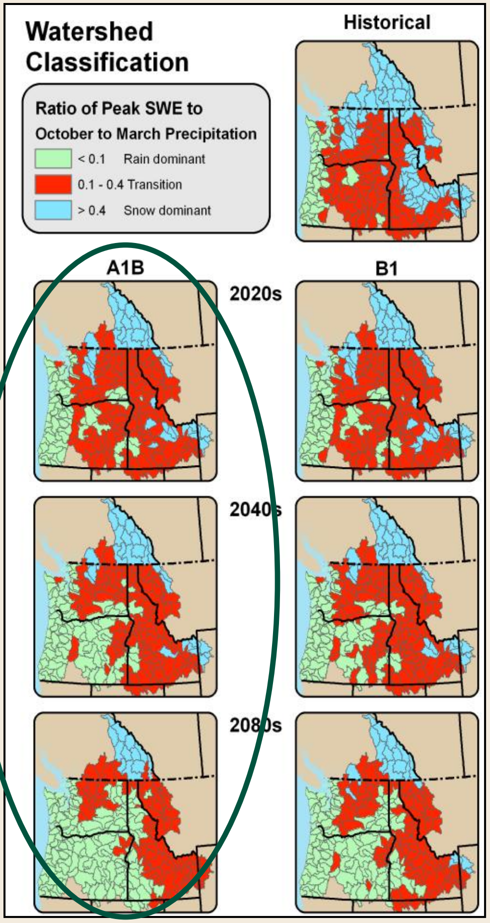
# Altered runoff/streamflow amount, timing, & frequency

- Future Projections (By 2100)
  - Streamflow 10-20 days earlier in AK/BC, 30-40 days earlier elsewhere
  - 100% loss of snowmelt-dominant basins in Cascades
  - April 1 SWE: -28% in Fraser (small increases at high elevations);

    -56 to -70% overall in PNW
  - Low flows exacerbated, e.g up to 50% decline in 7Q2 in PNW
- Implications
  - Salmon lifecycle
  - Flow effects exacerbated by increasing water temperature
  - Interactions with other stressors




*Source: Tohver & Hamlet (2010)*

Digital Vision

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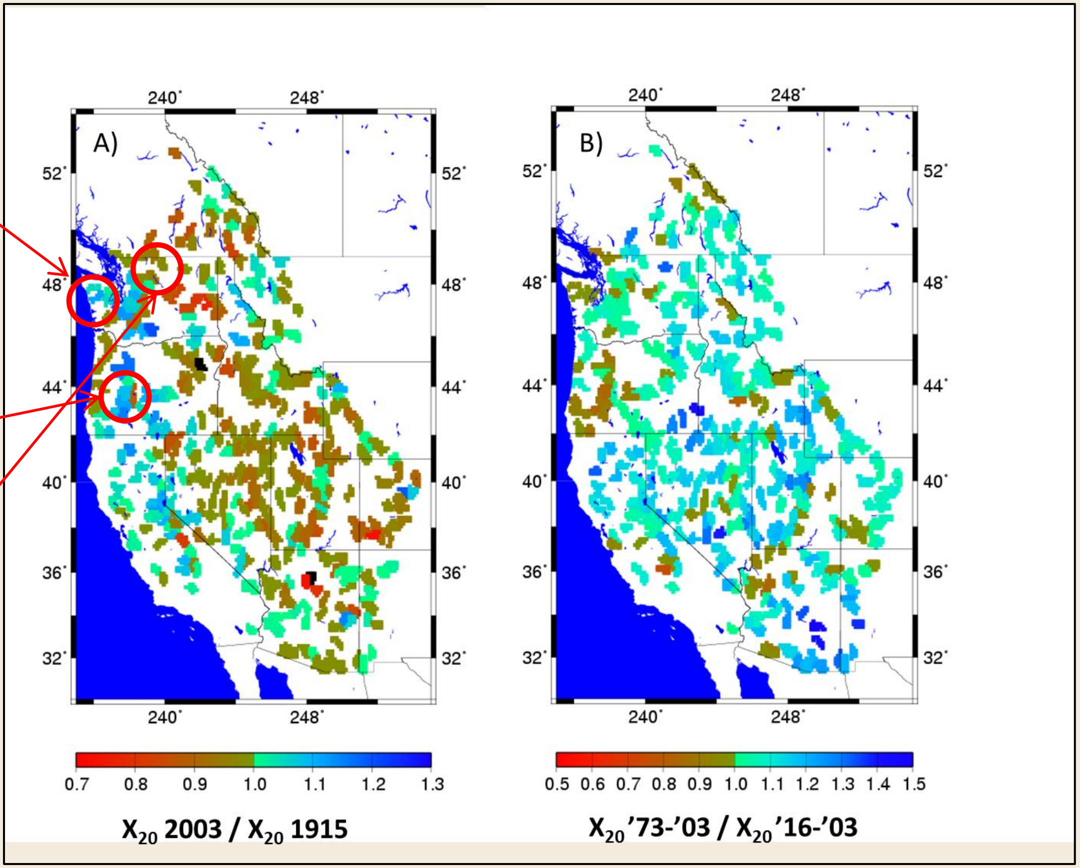
# Increased flooding & extreme flow

- Increase in rain-dominant
- Strong increase in warmer mixed rain-snow basins
- Likely unchanged in others

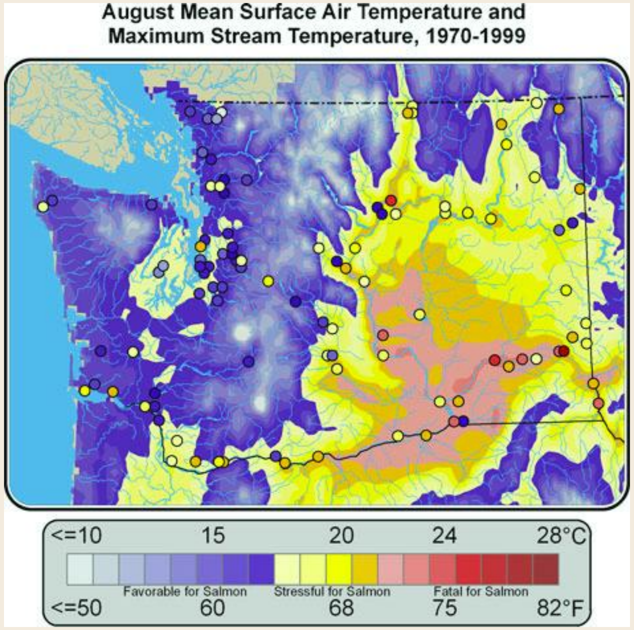


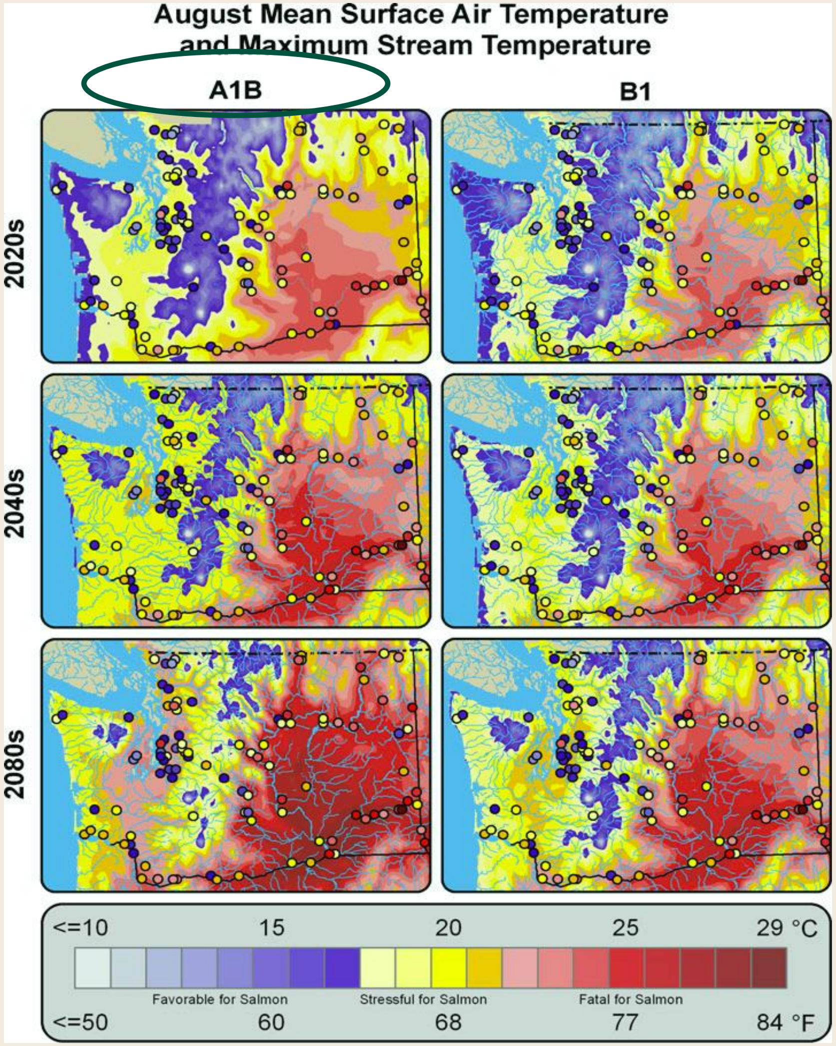

*Source: Hamlet, A.F.*

# Increased flooding & extreme flow

- Future Projections
  - 2040s @ Ross Dam: 50-year flood magnitude increases 15%
  - Floods from mixed rain-snow basins generally increase most
  - Klamath Basin: annual maximum-week runoff increases in lower basin, stable in upper basin
- Implications for salmonids using freshwater, esp. Nov-Jan

# Increased water temperature




- By 2080s, few watersheds favorable for salmon

*Sources: Mantua, Tohver and Hamlet (2010)*

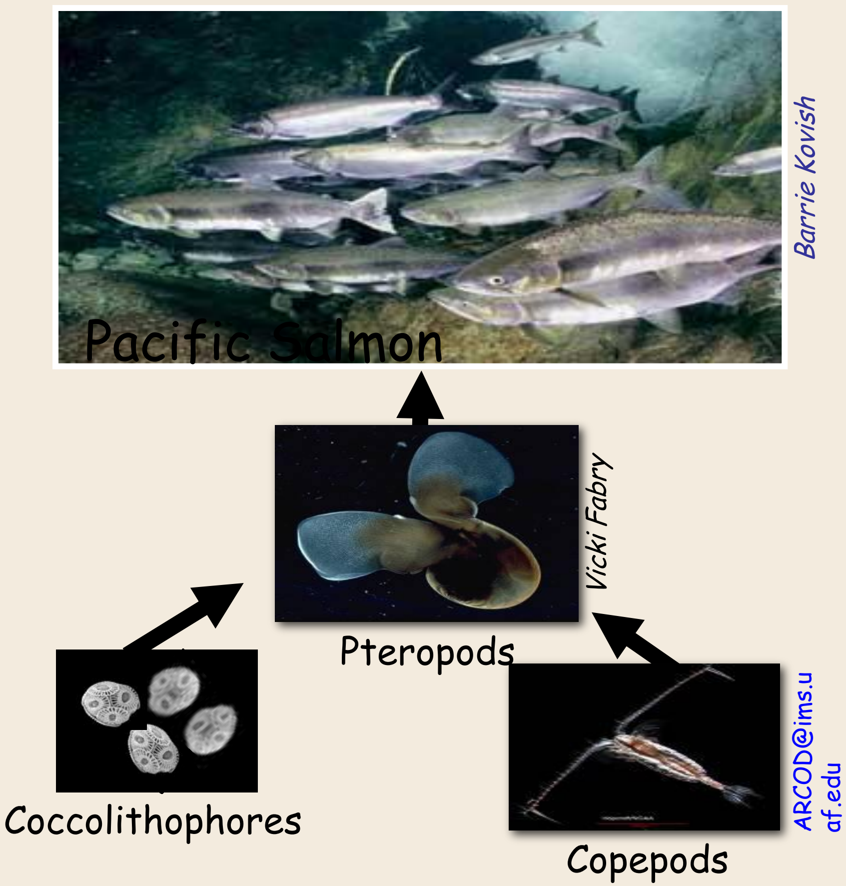
# Increased water temperature

- Tualatin River, OR: Stream segments with temperatures >68°F expand to upper reaches by 2100
  - Riparian vegetation mitigates increase in middle reaches
- Reduced ice cover in northern regions
- Implications
  - Effects on salmonids, aquatic productivity
  - Resilient riparian habitat as adaptation approach

# Effects: Salmonids

- Skagit Delta: Rearing capacity for juvenile Chinook would decline by 530,000 fish with 32” sea level rise
- Warmer oceans likely to promote decreased salmon populations
- Salmon prey appear particularly vulnerable to ocean acidification
- Stream temperature and flow effects likely to reduce migration success

# Effects: Declining pH & Salmon Prey




*Source: Richard A. Feely, NOAA*

- Significant and negative impacts on:
  - Survival, calcification, growth, reproduction
- Aragonite-shelled pteropods appear particularly vulnerable
- Potential impacts on food web
- Plasticity

# Adaptation Approaches: Habitat Loss, Altered Productivity, & Salmonids

Effects

- Habitat Loss
- Habitat Transition
- Declining Skagit Delta rearing capacity
- Warmer water & decreased salmon populations
- Declining pH & salmon prey ?

Adaptation Approaches

- Remove/prevent shoreline hardening structures
- Enhance sediment transport
- Establish ecological buffer zones
- Acquire rolling easements
- Restore or transition habitat
- Support/restore healthy beaver populations

# Adaptation Approaches: Salmonids, Habitat Loss & Vulnerability

Effects

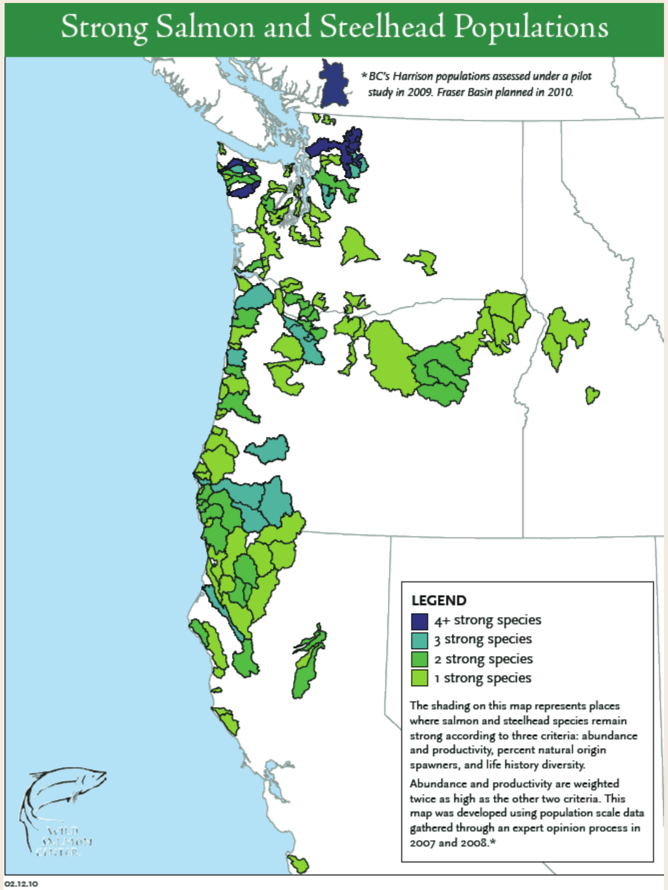
- Habitat loss and vulnerability
- Scouring
- Reduced migration success
- Reduced survival

Adaptation Approaches

- Remove/prevent shoreline hardening structures
- Establish ecological buffer zones & dispersal corridors
- Establish networks of protected areas
- Utilize environmental flow regimes
- Acquire rolling easements
- Restore or transition habitat

# Example: Salmon Strongholds

- Partnership effort
- 3 criteria determine strongholds
- Strongholds resilient to changing watershed conditions
- Climate-smart investment of scarce resources




*Source: Wild Salmon Center*

Digital Vision

# Example: Novel Indicators

**Table 20.** Novel indicators that may be sensitive to climate change.
*Modified from U.S. EPA (2008a, Table 3-2, p. 3-6 to 3-7) by authors of this report. Table continues on following page.*

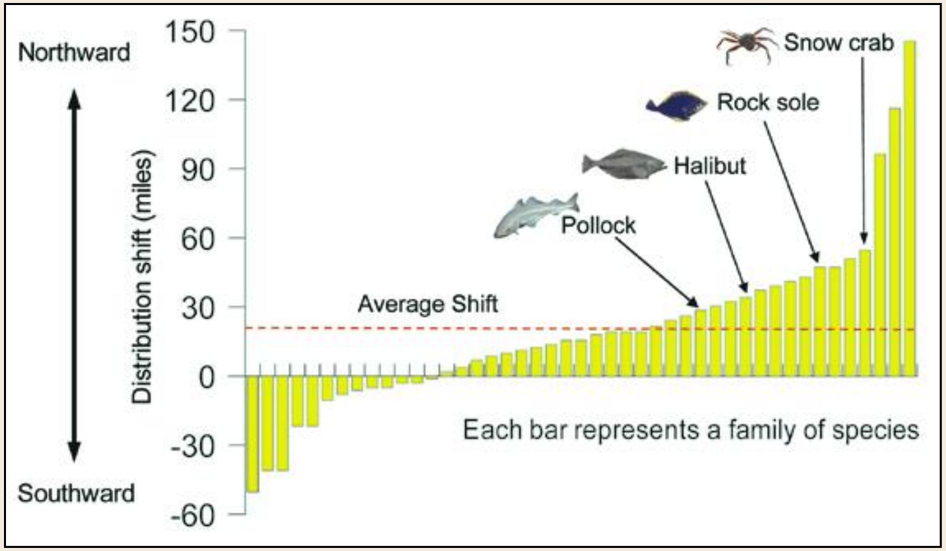
| *Category* | *Metric* | *Comments* | *References* |
|---|---|---|---|
| | Timing of emergence of mayfly species (also stonefly and caddis species) | Indirect effects on timing of salmonid feeding regime | Harper and Peckarsky, 2006; Briers et al., 2004; Gregory et al., 2000; McKee and Atkinson, 2000 |
| Phenology | Timing of trout spawning in warmer water | | Cooney et al., 2005 |
| | Rate of development and timing of breeding of the amphipod *Hyallela azteca* | | Hogg et al., 1995 |
| Longer growing season | Algal productivity | In northern areas a response to decreased ice cover and increased light penetration | Flanagan et al., 2003 |
| | Number of reproductive periods of amphipod species | | Hogg et al., 1995 |
| Life-stage specific | Sex ratios for certain insects (e.g. trichopteran *Lepidostoma*) | | Hogg and Williams, 1996 |
| | Smaller size at maturity and reduced fecundity of plecopteran *Nenoura trispinosa* and amphipod *Hyallela azteca* | From increased temperature | Turner and Williams, 2005; Hogg et al., 1995 |
| | Decreased salmon egg to fry survival | Increased turbidity from eroded sediment due to increased precipitation | Melack et al., 1997 |
| Temperature sensitivity | Reduced size of sockeye salmon | Reduced growth and increased mortality in higher temperatures as well as to lower plankton productivity | Melack et al., 1997 |
| | Increased growth rate of juvenile salmon in Alaska | | Schindler et al., 2005 |
| | Decreased growth rate of trout | | Jensen et al., 2000 |
| | Decreased survival of eggs of autumn-spawning salmon (e.g. dolly varden, brook trout, coho salmon) | Results in decreased abundance of autumn-spawning species, and/or change in relative composition between spring and autumn spawners | Gibson et al., 2005 |
| Hydrologic sensitivity | Decreased fry survival of pink and chum salmon due to earlier (late winter to early spring) peak flows | Earlier emergence and migration of pink and chum salmon fry to estuaries at a time when their food sources have not developed adequately | Melack et al., 1997 |
| | Differential mortality of drought-intolerant mussel species (e.g. *Lampsilis straminea claibornensis*, *Villosa villosa*, *Lampsilis subangulata*) | Results in changes in relative abundance, extirpation of vulnerable species | Golladay et al., 2004 |

- Identify novel local and regional indicators

# Effects: Range Shifts and Phenological Decoupling

- In 2005-2007, delayed plankton production linked to:
  - Cassin's Auklet nesting failure
  - Rockfish recruitment failure
  - Deaths of seabirds
  - Low survival of coho and Chinook

Marine Species Shifting Northward

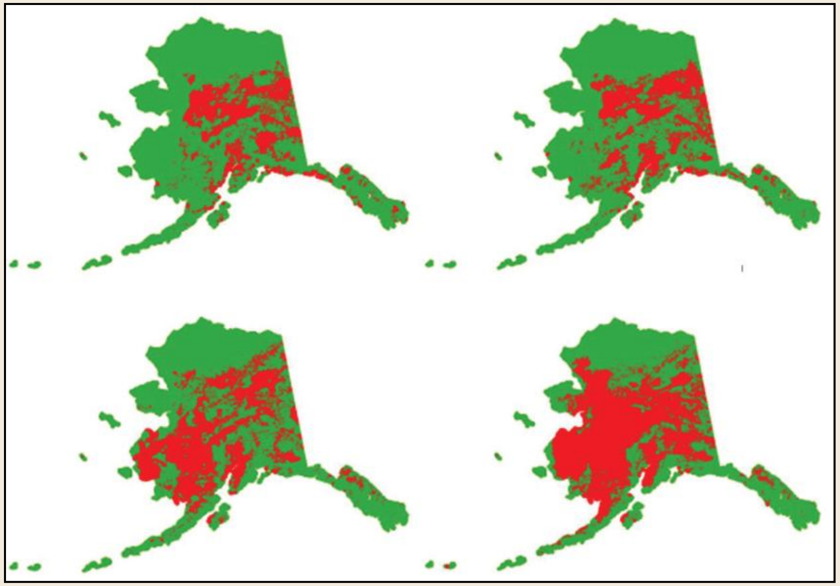



*Source: Karl, Melillo and Peterson (2009)*

# Effects: Range Shifts and Changing Biological Communities

- Trumpeter swans moving northward and westward
- Happening already?
- Tundra and trumpeter swans may be mixing at habitat interface

Potential expansion of trumpeter swan habitat



*Source: Murphy et al. (2010)*

Red: Swans present. Green: Swans absent.

# Adaptation Approaches: Legal, Regulatory, and Policy Change

Effects

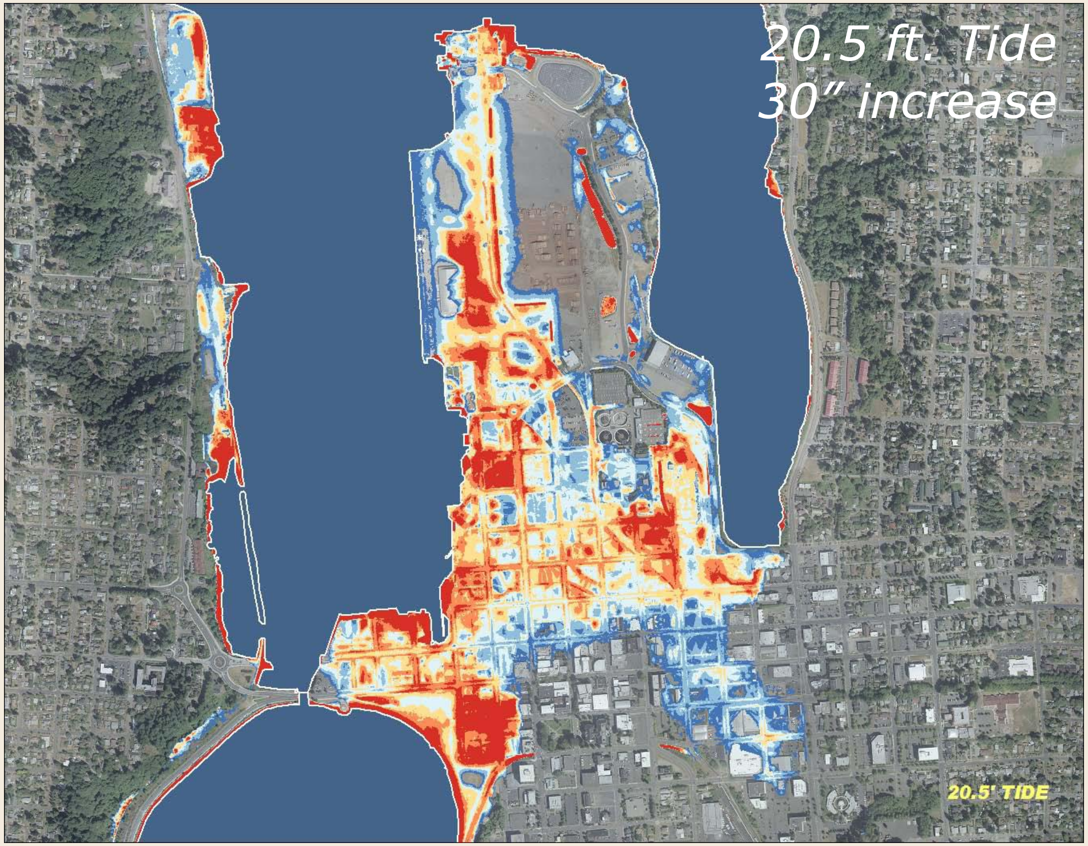
- Range shifts, decoupled phenology, & changing community composition
- Sea level rise, coastal erosion, & coastal squeeze
- Habitat loss & transition
- Declining ocean pH & vulnerability of salmonid prey & food web
- Altered hydrology
- Altered interaction with invasive species

Adaptation Approaches

- Create or modify laws, regulations, policies
- Incorporate climate science into decision making
- Implement coastal development setbacks
- Build institutional capacity

# Example: Planning for Sea Level Rise in Olympia

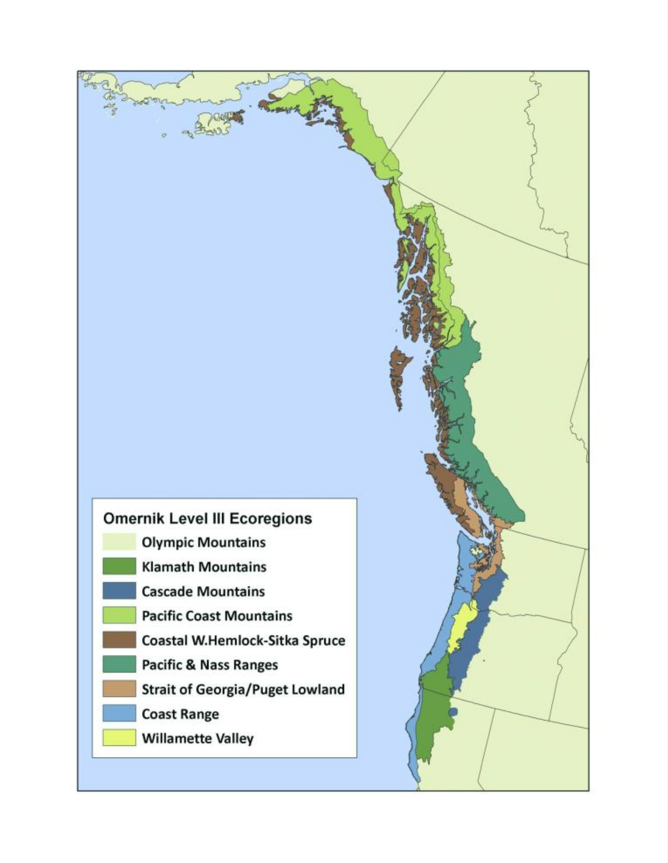
- Finer scale SLR simulations
- Raise floor elevations
- Update Olympia Comprehensive Plan,2010-2011
- Institutional framework



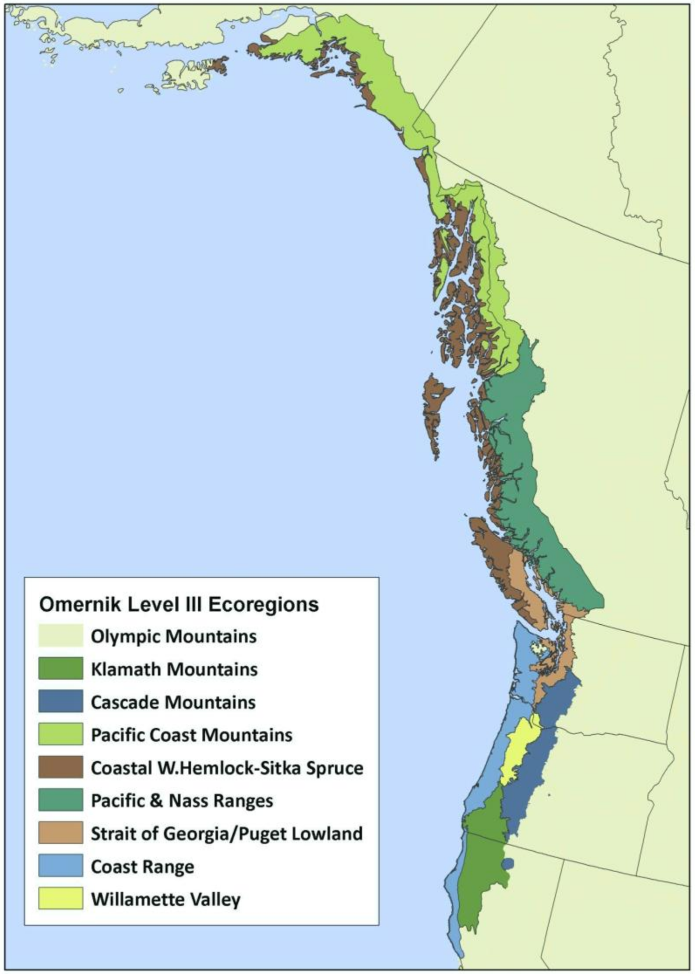

*Source: City of Olympia (2010)*

# Plans & Status of Phase II: Part 1

- 10 web-based focus groups
  - Organized by basin/ecosystem
  - 5 marine, 5 freshwater groups
  - 186 invites and counting (~115 sent this week)
  - Early 2012
- Goal: Identify climate-related science needs to inform NPLCC




*Source: U.S. Geological Survey*




*Source: U.S. Geological Survey*

- Marine Groups
  - SC/SE Alaska
  - BC Coast
  - Puget Sound/Georgia Basin
  - California Current (2)
- Freshwater Groups
  - AK/BC Coast
  - Pacific Coast/Nass Ranges
  - Puget Sound/Georgia Basin
  - Columbia River Basin
  - WA/OR/n. CA Coast Ranges & Drainages

# Plans & Status of Phase II: Part 2

- Two in-person focus groups
  - NPLCC-wide meetings
  - 1 marine, 1 freshwater group
  - <50 people each
  - Feb/March 2012
- In planning stages now
  - Seeking locations
- Same goal, but different focus
  - Will be guided by results of Part 1
  - Commonalities & differences across NPLCC region
  - Focus on cross-boundary collaboration?
  - Info will be used to finalize Phase I reports

# Conclusion

- NPLCC reports are reference documents
- Climate change effects already occurring and projected to continue
- Future impacts can be addressed by incorporating uncertainty and risk, acting early
- Focus groups are identifying science needs throughout region

# Acknowledgments


- U.S. Fish & Wildlife Service Region 1 Science Applications Program
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- UW Climate Impacts Group
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To access the Phase I Draft Final Reports, go to the "Adaptation Reports" section of www.nwf.org/climate-smart